

EXPERIMENTAL: National Ceiling and Visibility (NCV) Analysis Product Product Description Document (PDD)

Part I – Mission Connection

a. Product Description

The NCV product is a frequently updated representation of current ceiling and visibility conditions derived from METAR (ASOS) stations and GOES satellite information.

The product's ceiling and visibility fields are derived through nearest-neighbor interpolation of METAR data. This interpolation process, in effect, 'stretches' limited-area METAR observations across the broader domain between stations while an accompanying process accounts for terrain effects on ceiling height. The resulting field helps to visualize the 'likely' conditions at range from METARS.

The reliability of these fields generally degrades as distance from a METAR site increases requiring users to incorporate practical judgment in considering the representativeness of the product at increased distances from a METAR site.

The NCV product covers the conterminous United States (CONUS) and is updated every 5 minutes. The domain does not extend into the coastal waters, but does cover the Great Lakes. The product is built on the National Weather Service (NWS) National Digital Forecast Database (NDFD) 5 km grid. As the NDFD evolves to finer grid spacing in the future, the NCV product is planned to follow suit as required. The product can be updated at up to 5 minute frequency if future operational needs present a corresponding requirement.

b. Purpose/Intended Use

Weather continues to be a major economic and safety factor for all types of aircraft operations. The FAA has identified weather as being responsible for 70 percent of flight delays and approximately 40% of accidents.

The NWS collaborates with the Federal Aviation Administration (FAA) Aviation Weather Research Program (AWRP) toward achieving the common goal of transitioning new aviation weather products designed to mitigate economic and safety factors related to aviation weather into operational use.

The NCV product is one of several products emerging from this collaboration.

c. Audience

The CVA product users are expected to include a broad spectrum of aviation weather users, ranging from commercial airlines to general aviation and private pilots.

Professional meteorologists, airline dispatchers, flight service briefers and air traffic controllers also have similar needs for current en-route weather information. The NCV Analysis product seeks to help meet those needs through provision of a gridded analysis and a graphical display tool that supports the use and critical evaluation of product information.

d. Presentation Format

During the experimental period the product will be presented in image form on the evaluation webpage at <http://weather.aero/metars/>. When the product becomes operational, it will be available on an operational webpage and the raw data Gridded Binary (GRIB) Edition 2 will be available.

Details on GRIB Edition 2 may be found at: <http://www.wmo.ch/web/www/DPS/FM92-GRIB2-11-2003.pdf>).

e. Feedback Method

Feedback will be obtained through a link located on the evaluation webpage at <http://weather.aero/metars/>. Feedback will be solicited and analyzed beginning August 30, 2007 for a minimum of 30 days.

Part II – Technical Description

a. Format and Science Basis

Data processing

- Data ingest at 5-minute frequency gathers real-time ceiling, visibility, temperature and dewpoint observations from each of the METAR sites operating within the product's domain.
- Simple data quality checks done upon ingest identify missing data or data values that are outside the expected range for the sensor.
- Nearest neighbor interpolation populates the product grid with the most current ceiling and visibility observations.
- A cloud mask based on current GOES-11 and GOES-12 data is used to identify cloud-free (no ceiling) conditions in regions between METAR sites within the domain. These cloud free regions are entered as areas of unlimited ceiling on the domain grid.

- Confidence fields for gridded ceiling and visibility values are generated through tests utilizing distance from METAR observations, existence of METAR-to-METAR gradients, terrain height characteristics and dewpoint depression values.
- Analysis grids for ceiling, visibility, flight category and corresponding confidence fields for each parameter are currently output to a user-downloadable Java display application (see below). Ceiling, visibility and flight category fields are displayed on Experimental ADDS.

Data Access and Preparation for Interpolation

- The NOAA FTP site supplying access to real-time METAR data files is queried at the top of each hour and every five minutes thereafter. Through these queries NCV acquires the standard hourly METAR reports generated by each station near the top of the hour as well as the intermittent ‘special’ observations that are triggered by significant change in the value of ceiling, visibility, or other factors.
- The METAR reports are formatted and permanently archived. Provision is made in the tools and data structures under which METAR data are handled to accommodate future METAR reporting rates up to one per minute.
- Quality checks are applied to relevant observed parameters (e.g., ceiling and visibility) to assure that reported values are within range of reasonable, expected values. This check identifies sensor or data system failures that lead to gross corruption of the data value, such as a negative ceiling or visibility, or positive values that are out of range with respect to the sensor, etc. Suspect or corrupted data are flagged for later examination and withheld from use in the analysis system.

The Interpolation Step

Ceiling_{agl} and visibility are horizontally interpolated among all stations within the product domain. Three methodologies for interpolation have been explored: natural neighbor interpolation (Watson, 1992), nearest neighbor interpolation (Skiena, 1997), and Kriging (Cressie, 1991). Quantitative performance tests performed by the QAPDT (Fowler et. al., 2006) showed that among these techniques, nearest neighbor interpolation yields the best analysis results. Thus, nearest neighbor interpolation is used for this product.

- Nearest neighbor interpolation utilizes a simple, unsmoothed distance-related methodology and produces a piecewise, discontinuous output field that has the general appearance of a geometric jigsaw puzzle. While nearest neighbor interpolated fields are not the easiest to visually examine, the increase in resolution from 20 km to 5 km means results are now easier for the untrained eye to interpret.

Ceiling data reported in height above ground level (ceiling_{agl}) are converted to height above mean sea level (ceiling_{msl}) by adding METAR station height (as read from the NDFD grid) to each ceiling_{agl} value. Ceiling_{msl} is then horizontally interpolated between all the stations again. We perform two interpolations in two different spaces because we want to ensure unlimited ceilings and terrain obscuration are properly

handled. Converting between agl and msl space alters the value of unlimited ceilings as reported by METAR stations. It is judged that interpolation of non-unlimited and non-obscured ceiling values in ‘msl’ space is physically more viable than in ‘agl’ space. The former emulates interpolation along isentropic surfaces, which in general tend to vertically stratify clouds and weather systems. In contrast, ‘agl’ space is essentially a coordinate system defined solely by earth topography. Generally, clouds and weather follow isentropic surfaces rather than topographically defined surfaces. See Section 8 below for further discussion of interpolation errors.

Recovery of Ceiling_{agl} and Visibility

The values of ceiling_{msl} determined for each point on the NDFD grid by nearest neighbor interpolation are converted back to ceiling_{agl} by subtracting the terrain height value given for each grid point. Any negative values of these new ceiling_{agl} values are set to ”-1” and denote terrain obscuration by cloud. The values of visibility derived through interpolation across the NDFD grid require no further processing.

NCV Cloud Masking

Cloud masking and the clearing of interpolated ceiling in cloud-free gap areas currently utilizes GOES-11 and GOES-12 data in the 3.9 μ m and 11 μ m channels. As is common for this type of application, the cloud mask logic is built from a series of threshold and comparison tests applied to the data for each pixel in the scene. In general, the algorithm is tuned to conservatively detect clear conditions by contrasting 20 days worth of data. Output from the current NCV cloud mask is shown in Figure 3 below. The cloud mask is a derivative of the sophisticated technique developed at NASA/GHCC (Jedlovec et al., 2003). The Jedlovec method incorporates the use of thresholds that vary both seasonally and geographically.

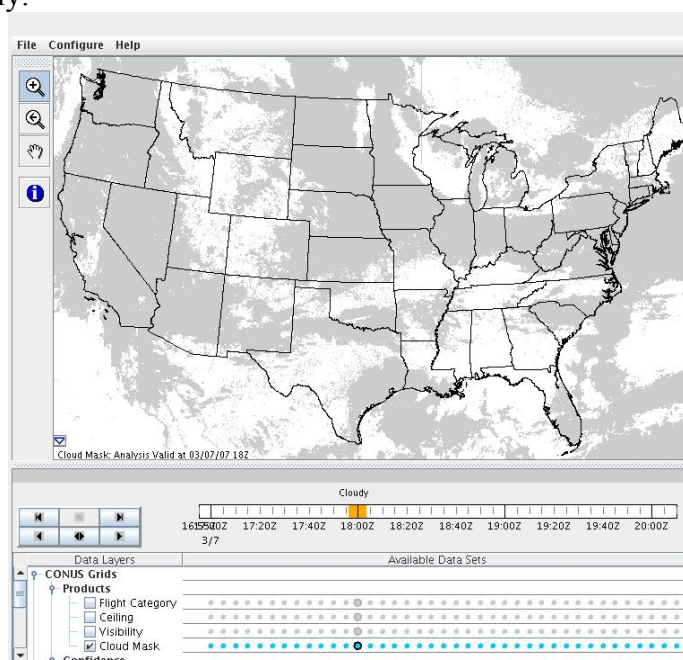


Figure 3. Example of the NCV cloud mask product derived from merged GOES-11 and GOES-12 data as presented by the Java display. Cloud coverage is given in white, while clear areas are shown in grey.

Satellite Blending

We utilize the newest satellite (GOES-11 and -12 separately) file within 45 minutes of the scheduled scan start time. If a file from each satellite is available, we combine the most recently available GOES-11 and GOES-12 cloud masks within that same time-frame. A new cloud mask is created only when new GOES-11 or GOES-12 data (not previously used in a cloud mask) becomes available. If a grid point is greater than 40 km from its nearest METAR and the cloud mask value is clear, we represent the ceiling at that grid point as unlimited. If a grid point is less than 40 km from its nearest METAR and has a value of unlimited from the agl-space interpolation and the cloud mask value is clear, we also represent that grid point ceiling as unlimited.

Establishing the Confidence Fields

Estimating uncertainty or confidence in regional analyses is an important complement to reducing it. After calculating values of ceiling and visibility for each grid point, a series of tests are applied to those grid points to determine how much reliance should be placed on those grid values. Each graphical confidence field is displayed in three colors relating to High-Medium-Low (H-M-L) confidence. Generally speaking, the confidence is an indication of where measurements of ceiling and visibility occur. To a reasonable degree, observations of the state of the atmosphere should extend from the locations of direct measurement. The tests applied to each grid point are discussed below.

- Calculate distance from the nearest METAR. As the range from the nearest METAR increases, the confidence at the grid point decreases from H to L. Derived dew point depression values influence the extent of influence a METAR station has on nearby grid points. Drier surface conditions tend to increase the limit of High and Medium confidence away from METAR stations. If neighboring METAR observations' categories do not agree, that difference reduces the confidence at points between them. This has the effect of lowering the ranges that define the regions of High and Medium confidence.
- Determine the elevation difference from the nearest METAR. This test provides a first-order representation of the uncertainty introduced by significant changes in elevation over relatively short horizontal distances. Grid points in mountainous areas are affected by this test. This test is applied after the test above and takes effect as a modification to results from the distance to METAR test. Modifications act toward less confidence. High values are dropped to Medium and Medium values are dropped to Low. There is no effect to previously-set Low values.

- Cloud mask clearing test. This is a correction-type test that is applied to the results of the two previous tests. This test's objective is to assign High confidence to regions that unambiguously show clear conditions using timely satellite information. This objective is mitigated somewhat by the age of the satellite data used to create the cloud mask. If the data is older than 45 minutes, the cleared pixels are assigned a confidence of Medium.

Once confidence fields for ceiling and visibility have been established, we construct the flight category confidence field. Each grid point is assigned a value that is the lower confidence of either ceiling or visibility.

The Integration Step: Digital Grids and Web Displays of Ceiling, Visibility and Flight Category

Analysis product displays and output grids are updated every five minutes to take into account recent METAR reports (e.g., Special reports which may arrive at any time) and the most recent GOES satellite scan, which is updated at approximately 15 minute intervals.

By definition, Flight Category is broken into four condition ranges:

- Visual flight rules (VFR)
- Marginal visual flight rules (MVFR)
- Instrument flight rules (IFR)
- Low instrument flight rules (LIFR)

Flight category is derived from ceiling and visibility conditions according to the following category definitions:

- VFR: ceiling > 3000 ft and visibility > 5 statute miles (sm)
- MVFR: $1000 \leq \text{ceiling} \leq 3000 \text{ ft}$ or $3 \text{ sm} \leq \text{visibility} \leq 5 \text{ sm}$
- IFR: $500 \text{ ft} \leq \text{ceiling} < 1000 \text{ ft}$ or $1 \text{ sm} \leq \text{visibility} < 3 \text{ sm}$
- LIFR: ceiling < 500 ft or visibility < 1 sm

GOES Data Processing

The present role of GOES-11 and GOES-12 data in the analysis system is conceptually quite simple – to distinguish cloudy from cloud-free (no ceiling) regions within the gap areas between METAR sites. The term ‘cloud masking’ is frequently applied to the foregoing cloud detection process. The resulting information on clear conditions in gap areas is then incorporated into the final analysis grids and displays in the integration step (red box in Fig. 1). In doing so, we take a step to guard against over-representation of low ceiling conditions interpolated across these gap areas.

The simplicity of the cloud masking objective somewhat obscures its functional difficulty. The state of the art in cloud masking today is quite imperfect, reflecting a range of difficulties including the following:

- Cloud detection during the day/night transition suffers from reduced reliability.
- Optically thin clouds can often be missed, particularly at night.
- Performance is likely to differ between detection of high and low clouds.
- The thermal and radiative characteristics of background scenes complicate cloud detection.
- Latitudinal and seasonal differences in the thermal radiative characteristics of the surface (background) interfere with cloud detection, requiring appropriate compensation within many detection methodologies.

In the context of NCV use, the potential to over-report the areal extent of restricted ceiling conditions is undesirable, but does not lead to the far more dangerous problem – failing to register a hazardous ceiling condition. The latter can result from false detection of clear conditions by satellite if that satellite data is used to truncate the areal extent of an interpolated ceiling field.

b. Product Availability

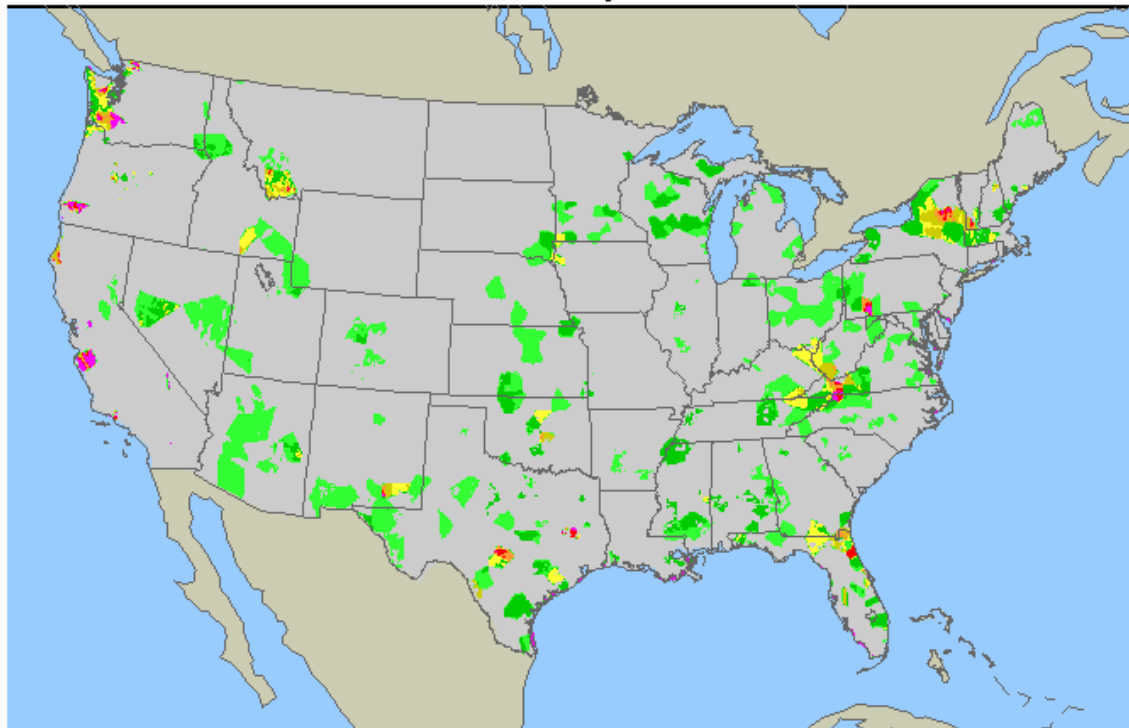
c. Addition Information

Examples of the NCV product primary fields are shown in Figures 1 through 3 below.

This National Ceiling and Visibility Analysis is an automated experimental product presented exclusively for non-operational evaluation by trial users. The product is not proven or authorized for operational use and does not substitute for ceiling, visibility, or obscuration information contained in AIRMETS.

Ceiling in ft AGL

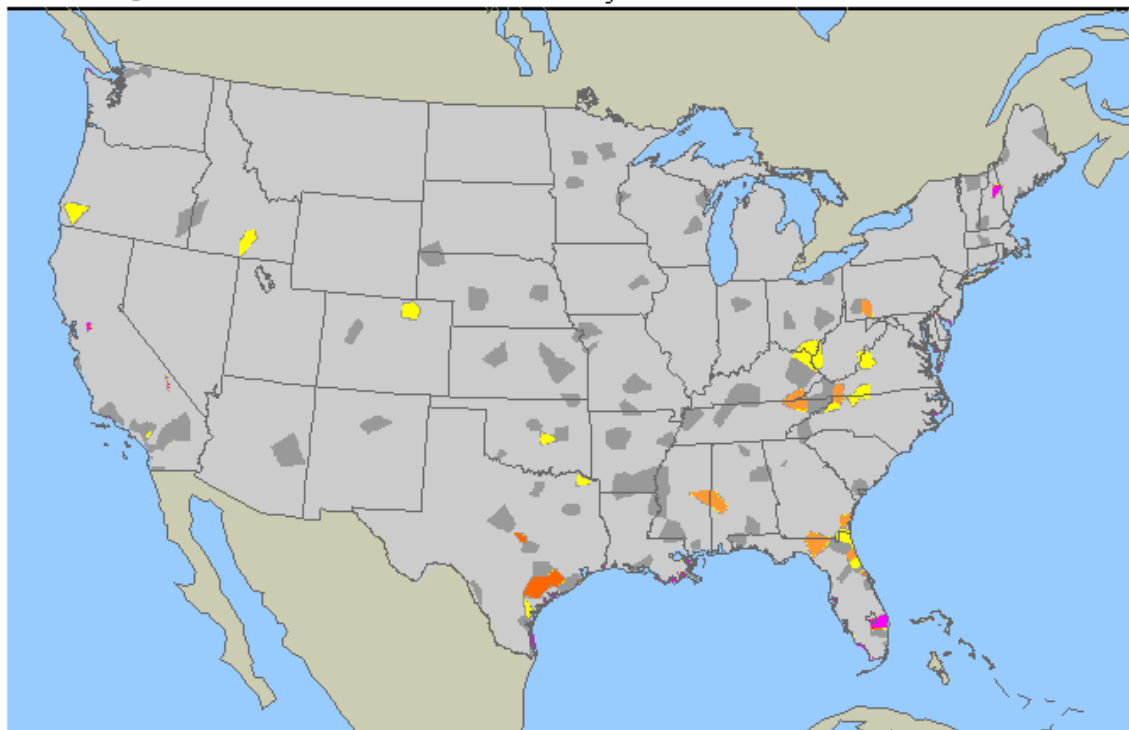
Analysis valid 1925 UTC Tue 24 Jul 2007



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Visibility in Miles

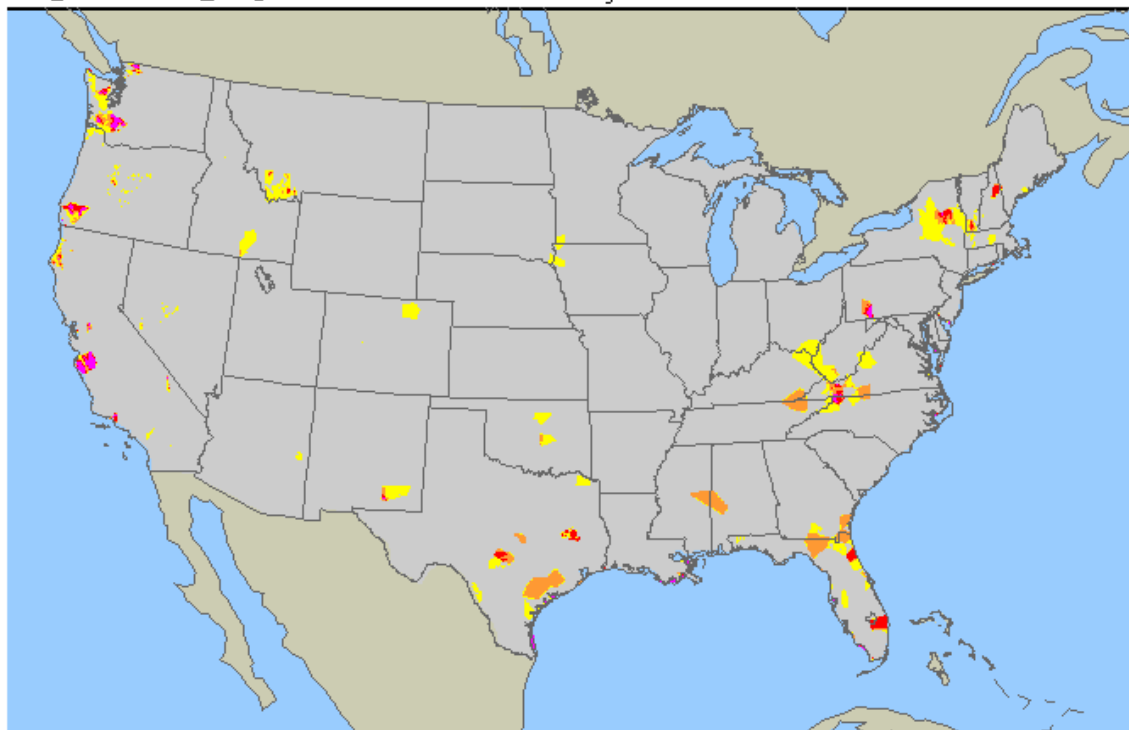
Analysis valid 1925 UTC Tue 24 Jul 2007



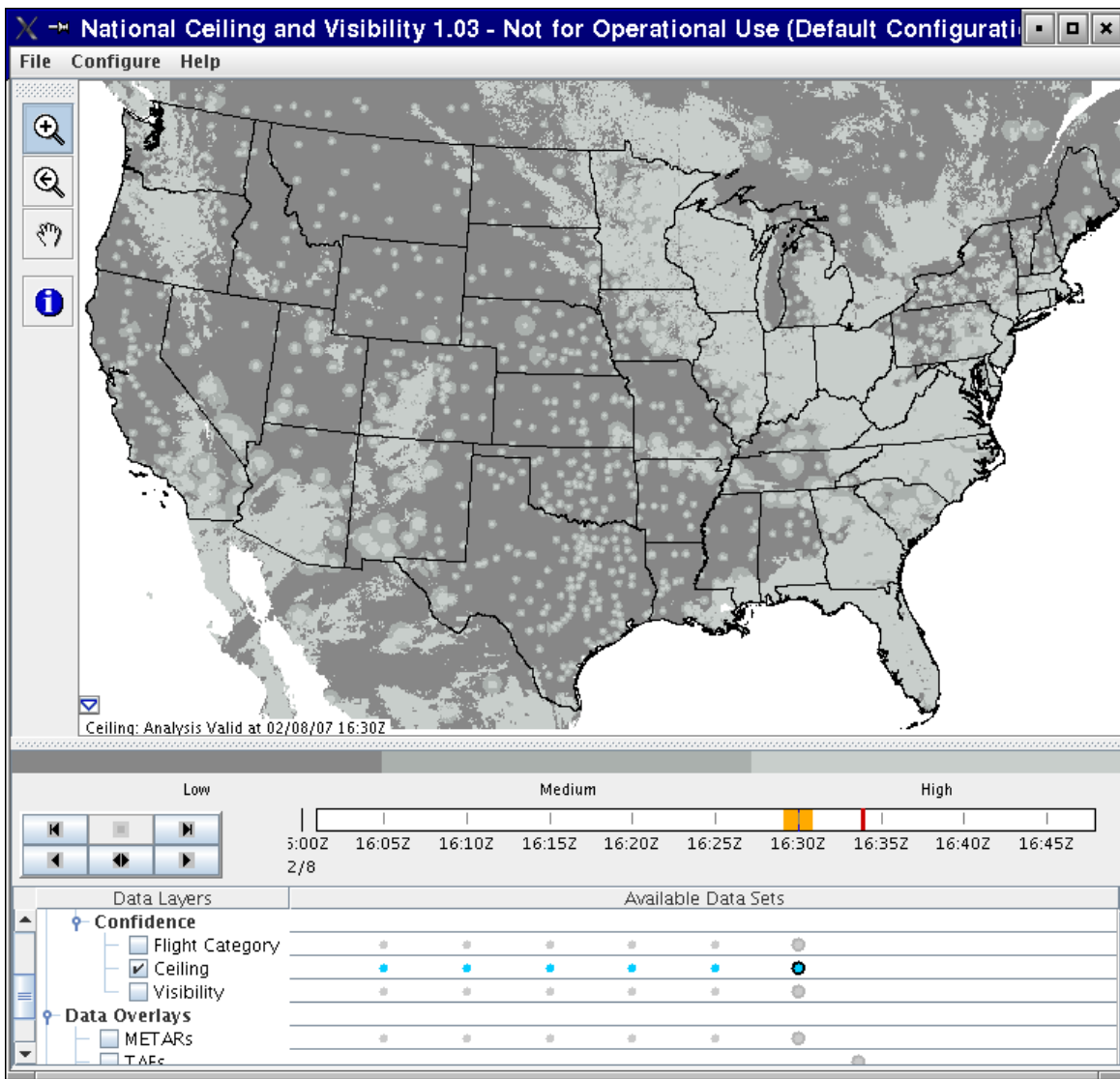
This National Ceiling and Visibility Analysis is an automated experimental product presented exclusively for non-operational evaluation by trial users. The product is not proven or authorized for operational use and does not substitute for ceiling, visibility, or obscuration information contained in AIRMETS.

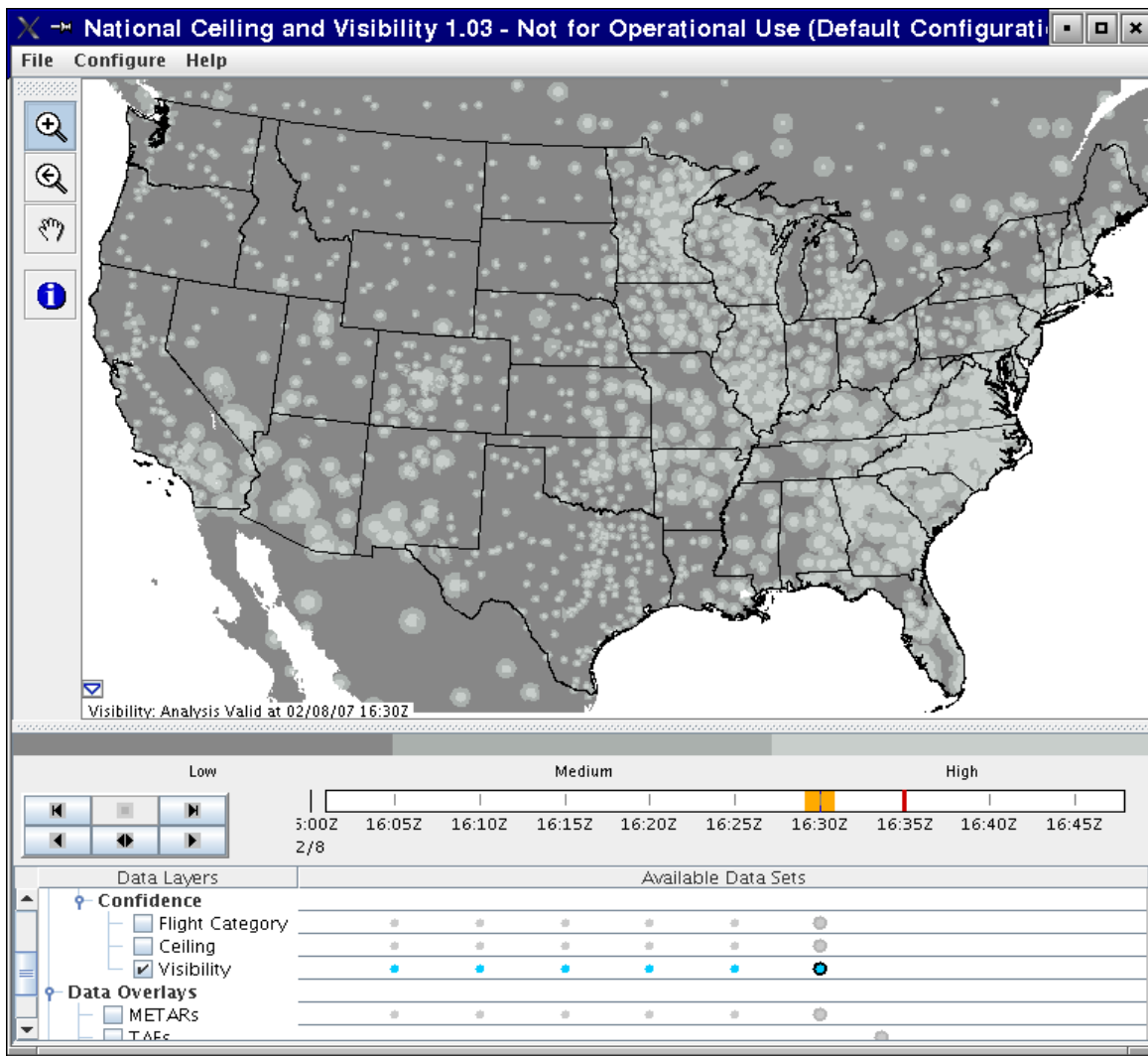
Flight Category

Analysis valid 1925 UTC Tue 24 Jul 2007



Figures 1 through 3. Views of the NCV Analysis product display. Figure 1: Ceiling. Figure 2: Visibility. Figure 3: Flight Category.





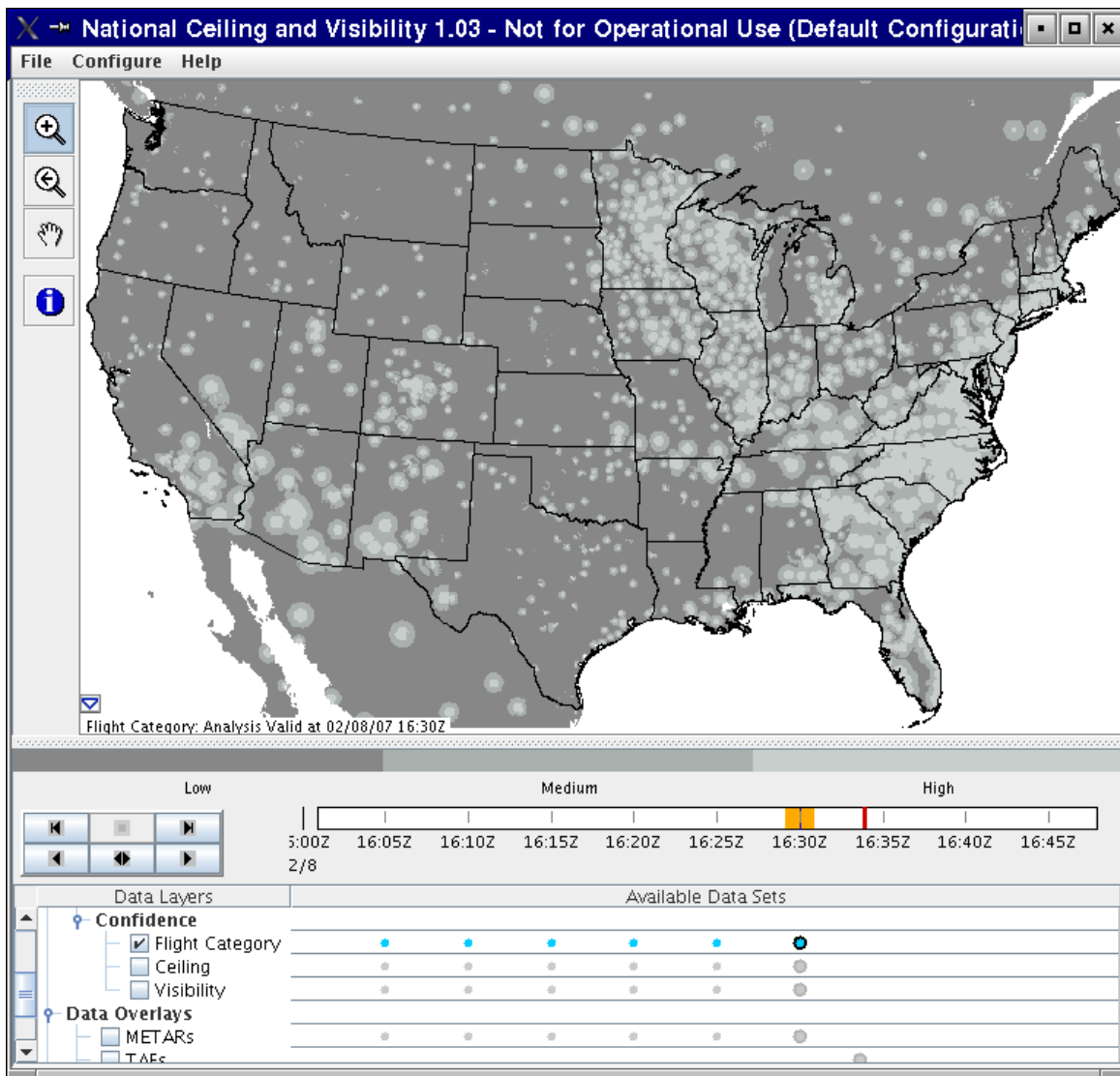


Figure 2. Views of the Analysis product Java display. Upper left: Ceiling. Upper right: Visibility. Lower: Flight Category.

Part III - Future Data Sources

Additional real-time data can improve analysis system performance, and NCV plans include use or exploration of the following data types:

- PIREPS, though limited in number for ceiling and visibility conditions, can be an important source of direct observational data. We anticipate incorporating an overlay of recent PIREP data in our display and output grids. Further use of PIREP data can be considered, pending our experience with these data.
- NEXRAD and TDWR radar data present information important to precipitation-induced visibility reduction. Future work will capitalize on current research in radar-based visibility estimation.

- POES and future NPP (NPOESS Preparatory) polar-orbiting satellites can provide high-quality additions to GOES satellite data during limited CONUS overpass times.
- Cloud top and cloud base information from satellite data might allow us to improve upon our current cloud mask implementation. This additional information could also provide increased guidance on our level of confidence when reporting conditions away from surface METAR stations.
- Observational networks related to agriculture, highway weather and other applications may offer some opportunities for additional sources of visibility or other data. Ceiling is not generally a measurement made within these networks. Data quality certainly becomes an issue when looking at these ancillary data sources, and we expect that some data would be found inadequate or impractical for use due to quality issues. We will proceed with caution as we consider new data sources.

Part IV - Representativeness Issues: Discussion of Current Status and Future Directions

Both ceiling and visibility are complex, patchy, discontinuous fields in nature. Low ceiling or visibility measured at one METAR site may or may not have relation to the values observed at a neighboring site. In such cases it is at best ‘an educated guess’ to populate intervening grid points by interpolation. However, since neither ceiling nor visibility can be practicably measured by continuous observations across a broad area, today’s state of the art for regional analysis of these fields must begin with some form of interpolation or extension beyond the point observations available at METAR locations.

Ceiling

In the case of ceiling, the NCV analysis product utilizes satellite observations to help determine where cloud-free areas exist between METAR sites. The cloud masking methods in use are discussed in Section 6. However, once determined through use of these methods, the cloud-free areas found are used as a mask to impose ‘no ceiling’ conditions on the affected portions of the interpolated ceiling field. In this manner, the satellite data improves the representativeness of the ceiling field. However, this improvement is limited in its impact, for we have no improved information as to the height of the ceiling in the *cloudy* areas that occur between METAR sites. In those areas, the ceiling could in principle be high – above the IFR threshold – or low, resulting in restricted flight conditions or even terrain obscuration. Simple cloud mask methods are no help in estimating ceiling height in cloud. Thus, at present we can only rely upon interpolations as *estimates* of ceiling height in this situation.

Several avenues for improving the representativeness of ceiling analysis information are outlined below:

- Model hydrometeor fields carry ceiling information that can be used to augment real-time observations for analysis. As assimilation of surface observations continues to advance in the RUC model and be explored in the Rapid Refresh model, 1 and 2 hour RUC forecasts demonstrate growing skill in defining realistic ceiling fields. As part of the model evaluation work ongoing within NCV, we look to define advantageous use of model analysis fields to improve ceiling information within the NCV analysis product.
- NCV work carried out by Richard Bankert of NRL explored the application of satellite, surface and model data to improve the diagnosis of ceiling height in cloud-filled gap areas lacking direct ceiling observations. Early results of that work are encouraging (Bankert *et al.*, 2004), but have not yet progressed to the point where the benefits of application across diverse conditions within the CONUS are established.
- In addition, there is a small opportunity to be gained when the heights of low cloud *tops* can be determined through satellite IR brightness measurement techniques, for example. In this situation, an upper limit on ceiling height emerges, and improves (if only slightly) the information we have to estimate ceiling height. For this reason, NCV work during the post-D4 period will address potential use of current and emerging NESDIS cloud top height products and other techniques for estimating cloud top height.

Visibility

The representativeness of interpolated visibility in regional analyses is likely to be just as uncertain as that of ceiling. The prevalent causes of reduced visibility – fog, haze, precipitation, and even blowing dust or snow – characteristically show significant structure on scales much smaller than the spacings of tens to hundreds of km between most METAR sites. Fog, for example, may reduce visibility over areas with dimensions as small as hundreds of meters or as large as many tens of km.

NCV's approach to visibility is similar to that outlined above for ceiling. Interpolation of visibility values between METAR sites, while not realistic in all cases and over all the scales of interpolation imposed by the spacings among METAR sites, *does* more often than not populate the analysis grid with improved information, and also improves the users' ability to recognize aspects of the regional pattern of visibility.

A number of avenues hold promise for future improvement in the representativeness of regional analyses of visibility. For example:

- Fog detection via satellite has potential to improve monitoring and better define the bounds of fog-related low visibility areas between METAR sites. However, we note that satellite fog detection is also complicated by its own set of uncertainties, including low optical depth, discrimination of winter fog from a snow-covered ground surface, and discrimination of fog from low cloud. Study of these issues, which help define the state of the art, will proceed during the post-D4

period, and we expect to implement use of NESDIS and/or CIMSS operational fog and low cloud detection methods in the future.

- Definition of low visibility areas resulting from precipitation (most often snow) can benefit from use of NEXRAD and TDWR radar data, which provide independent measurement of the areal extent and approximate intensity of visibility-reducing precipitation. Farther in the future, the improved recognition of hydrometeor phase, size and type offered by the polarimetric capabilities to be incorporated on NEXRAD radars will advance this effort considerably. We expect to explore the use of NEXRAD data to refine visibility guidance during the post-D4 period.
- As outlined above for ceiling, model fields of near-surface humidity and hydrometeors also carry information that can be used to augment real-time observations used for analysis. Improvements in the assimilation of surface observations further benefit this information. We plan to explore use of the RUC (and Rapid Refresh, when available) analysis fields to improve visibility information during the post-D4 period.

Smart Interpolation for the Future

While the discussion above has centered upon means to improve the raw data used in the interpolation process, a second strategy is to improve the interpolation procedure itself. For example, it would be beneficial to steer the interpolation process away from actions that would be avoided by a knowledgeable analyst. One step toward accomplishing this is to take into account meteorological and geographic barriers and regimes, and to engineer means for a ‘smart’ interpolation that avoids spanning these. This is an effort for future development work.

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